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A Helmet Mounted Display to Adapt the Telerobotic Environment to Human Vision

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Abstract

A Helmet Mounted Display system has been developed. It provides the capability to display stereo images with the viewpoint tied to subjects head orientation. This type of display might be useful in a telerobotic environment provided the correct operating parameters are known. The effects of update frequency were tested using a 3D tracking task. The effects of blur were tested using both tracking and pick-and-place tasks. For both we found that operator performance can be degraded if the correct parameters are not used. We are also using the display to explore the use of head movements as part of gaze as subjects search their visual field for target objects.

Introduction

Stereo displays are now commonly used as a visual interface for telerobotic systems because they provide better telepresence than monoscopic displays [1],[3],[13]. The hardware has improved considerably since stereo displays have been used, but our knowledge of the perceptual aspects of using stereo display systems remains very limited. The video images from a remote site could be degraded by a number of factors such as blur, noise, contrast or illumination changes that could differentially affect performance with stereo and non-stereo displays. The effects of these degradations on performance has not been closely examined except in the case of contrast [4]. Without this knowledge, stereo displays might be used in inappropriate situations, i.e. where an unnecessary increase in performance is offset by increases in cost, transmission bandwidth or system complexity [5].

In order to test the usefulness of our Helmet Mounted Display system, we decided to explore how changing the parameters of the display affected the performance of some representative telerobotic tasks. Previous studies have shown that increasing the apparent interocular distance of the display from zero, decreases mean completion time for a pick and place task.[1] Here we explore the effects of different update frequencies and blur on performance.

The Helmet Mounted Display

Helmet mounted displays were designed as a more comfortable interface that provides the human operator with telepresence, i.e. the feeling that he/she is in the remote environment and controlling the manipulator directly. The helmet is equipped with a stereo display and can detect the operator's head motions in order to move the remote stereo cameras in a similar fashion. Our experiments simulated the remote environment with computer graphics and standard stereoscopic display formulas [1].

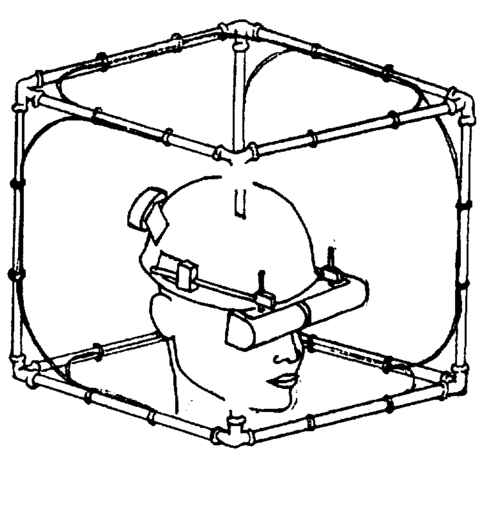

Figure 1. Helmet Mounted Display This system provides a stereo view through two video camera viewfinders, one for each eye. Head orientation is measured with the Helmholtz coil system. (outer coils)

Two degrees-of-freedom are detected by the head orientation sensing device, horizontal and vertical rotations. The sensing system is comprised of two magnetic Helmholtz coils with normal magnetic fields and a sensing coil mounted on the inside top of the helmet. Each field coil generates a different sine wave magnetic flux (50kHz for horizontal, 75kHz for vertical). The induced flux in the sensing coil is then amplified and separated into the respective components. The magnitude of each component is dependent on the head orientation with respect to the corresponding field coil [2].

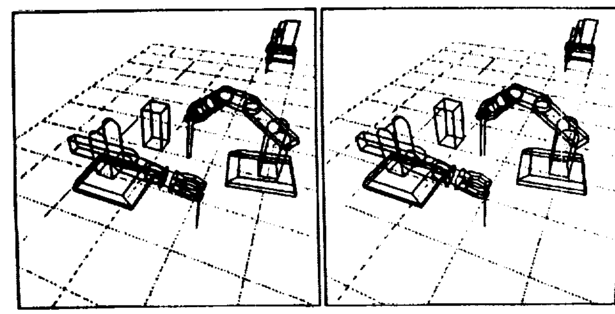

Figure 2. Robot Manipuation Task. Stereo images and head coordinated views give operators a sense of telepresense. The relationship between robots and objects might be more easily seen in such a display.

The stereo display is comprised of two 1-inch viewfinders (Sony VF-208) mounted on the helmet by means of a 5 degree-of-freedom frame. The frame has three orthogonal slidings and two rotations. Each viewfinder also has a converging lens which forms the virtual image of the stereo pair 25cm behind the actual display screen. The sixfold magnification of the lens makes the display screen look like a 6-inch screen (33 degrees wide). When adjusted appropriately, most observers can fuse the two images into a single three-dimensional image. A 0.5 kg counterweight was fastened to the back of the helmet to counterbalance the viewfinders.

Update Frequency Requirements

One important goal of using a HMD system is to provide the user with a stronger sense of telepresence from the enforced correlation of head movements and displayed view direction. If the scene is not updated rapidly enough this correlation (called Space Constancy in the realm of natural human gaze movements and psychophysics [15]) might be lost, but in a telerobotic setting, limitations in hardware or in signal bandwidth might limit the update speed. We suspect that there is some band of update frequencies above which there is no noticeable change in the display quality but below which operator performance falls to unacceptable levels. It is this range where performance is affected by update frequency that we explore here.

We tested the effects of update frequency by using a 3D tracking task. Figure 3 shows a sample display from the experiment. The subjects viewed a virtual space from above the edge of a ground grid. In the space was a box target and a spherical cursor. The cursor was controlled through two joysticks. The subjects were asked to keep the sphere in the box. The target moved in a pseudorandom pattern in three dimensions. The target trajectory was a sum of 11 sinusoids with frequencies from 0.007 Hz to 5.8 Hz. The amplitudes simulated a low pass filter with a corner frequency of about 0.08 Hz. The field of view of the scene extended to 60 degrees so that when the target was at the extremes of its motion, head movements were performed to keep the target in the visual field. Under these conditions each subject carried out the task for 10 update frequencies ranging from 15 Hz to 0.5 Hz presented in a random order.

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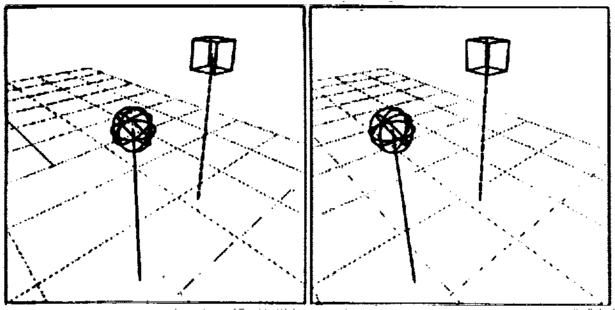

Figure 3. 3D Tracking Tasks. The subject tries to keep the ball inside the box that continually moves in a pseudorandom pattern. The ball is controlled by two joysticks.

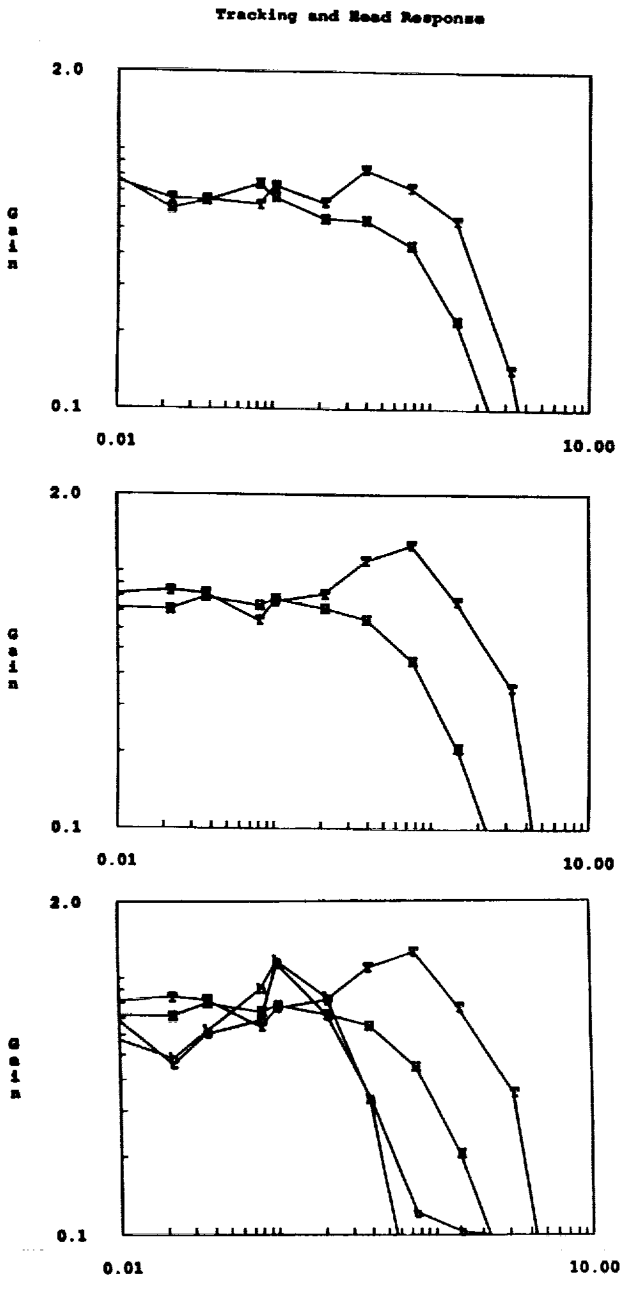

Figure 5. Tracking Response. Two subjects (top and middle panels) show that the tracking [T] has a higher bandwidth than the head movements [H] at the highest update rate. At the lowest update rate (bottom panel) tracking [t] and head movements [h] have the same bandwidth.

Due to the high frequency content of the input signal, the normalized rms error is high even for the fastest update frequency. We normalized the rms error to the situation where there was no operator input. Therefore, error values greater than one indicate tracking worse than doing nothing at all. This situation occurs for the lowest group of update frequencies that we tested. Figure 4 shows the rms error for all the update rates tested.

We measured both the cursor position and the head movements even though the subjects were not told to track the target with their head. Figure 5 (top and middle) shows the response of two subjects at the highest update frequency for both tracking and head movements. It shows that the bandwidth of the head movements is smaller than that of the tracking. This is not unexpected since the subjects were only using head movements to assist in the tracking. However, the bottom panel, which also shows the response at the lowest update frequency, indicates that manual tracking degrades to the same bandwidth as head movements. Even so, figure 6 shows that at a particular input frequency, around the corner frequency of the tracking at the highest update rate, the manual tracking is better than head movements throughout the experiment. In general we discovered the not surprising result that if the image doesn't change with head movement, subjects tend not to move their heads. But, they seem to try to track the target even after the update rate slows considerably.

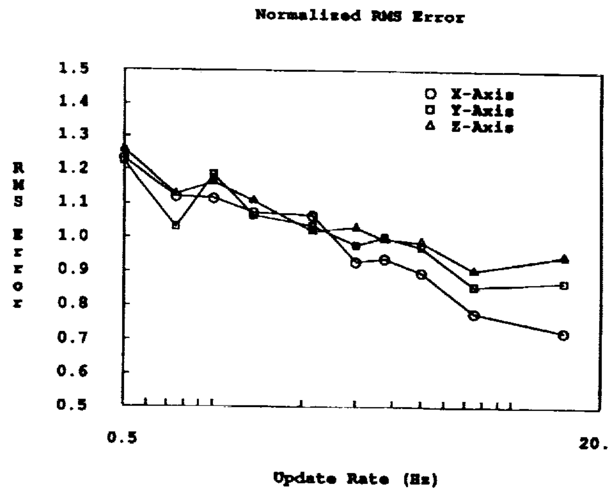

Figure 4. Tracking Performance. The rms error is normalized to the case of no response. As the update frequency falls the rms error rises; at the lowest frequencies the tracking is worse than no response.

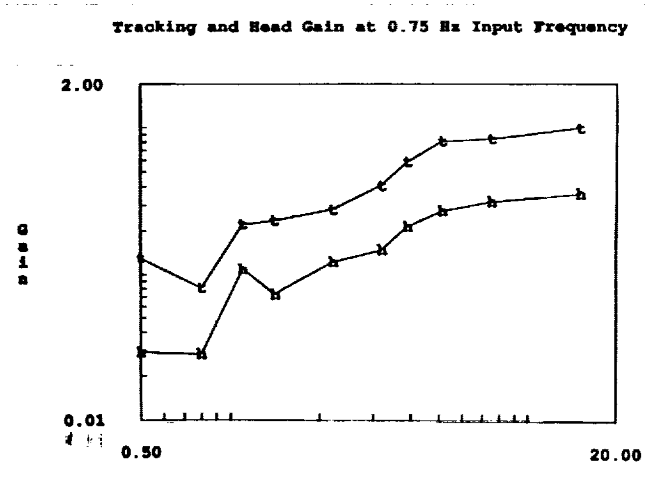

Figure 6. Tracking Gains. The gains of the tracking and head movements for an input frequency of 0.75Hz across all update frequencies shows how the gains fall as update frequency goes down. It also shows that tracking is more accurate than head movements, this is because the subjects were not asked to track the target with their heads.

The Effects of Blur on Task Performance

Psychophysical experiments can provide a basis for predicting performance changes under these degrading conditions. For example, experiments studying the effect of blur on human stereoacuity have shown that target blur reduces stereoacuity. Most of these experiments used blur induced with spectacle lenses and measured the stereoacuity with a depth-discrimination test such as the Howard-Dolman test [6]-[9]. Blur caused by spatial frequency filtering [8] has also been shown to cause similar degradations in stereoacuity. In addition, it was found that blur of only one eye resulted in a greater deficit than equal amounts of blur in both eyes. Figure 7 (top) shows some of the results from Lit's and Westheimer and McKee's experiments with monocular and binocular spectacle blur. The data for binocular blur is shown by the solid plot symbols. Stereo displays differ from monoscopic displays in that they also use the disparity cue to display depth. Therefore, we conclude that stereoacuity, or the ability to discriminate two points in depth, is important in telemanipulation. Furthermore, we would expect operator performance to decrease as the one or both of the images were increasingly blurred.

To confirm this hypothesis, we examined the effect of visual target blur on the performance of simulated telerobotic tasks. Using the helmet mounted display described previously, two generic telerobotic tasks were simulated, a pick-and-place task and three-axis tracking. Head movements were not needed to view the entire scene in these experiments. Also, the binocular disparity in the scene provided the only cue to the depth of the targets in space. The pick-and-place task required the operator to grasp objects that were floating within the workspace and put them in a box on the floor. Performance was measured by the average time to complete the task for 20 objects. In the three-axis tracking task, the operator followed a randomly moving target as closely as possible with a cursor controlled by two displacement joysticks. Performance was measured by the rms error between the target and the cursor. The error was normalized by the error value associated with no movement of the operator's cursor.

These tasks were performed under bioptic (binocular without disparity), ideal stereoscopic and blurred stereoscopic viewing conditions. The simulated scenes were drawn with lines and dots in order to reduce the number of computations needed to display and update the scene. Monocular target blur was induced by spectacle lenses and used in all the trials. This was done to ensure that a reduction in stereoacuity and performance occurred. Since disparity was the only depth cue present in the scene, performance was expected to deteriorate in a similar fashion to stereoacuity. Our results are directly comparable to the psychophysical results since the method for inducing blur is the same.

In Figure 7 (middle and bottom) the results show that performance of the pick-and-place and three-axis tracking tasks decreased when 2 diopters of monocular blur was present. The performance fell to the level of performance for the bioptic(B) viewing condition. Psychophysical results show that stereoacuity becomes 3-15 times worse with the addition of 2 diopters blur. This suggests that moderate reductions in stereoacuity can be enough to eliminate the advantage of using stereo displays. This helps explain how early experiments comparing stereoscopic and monoscopic displays did not find any performance differences.[14] It is possible that the stereo displays were not carefully adjusted such that the images seen by the operator was blurry. As a result, their stereoacuity was degraded to the point that the stereo display was not useful.

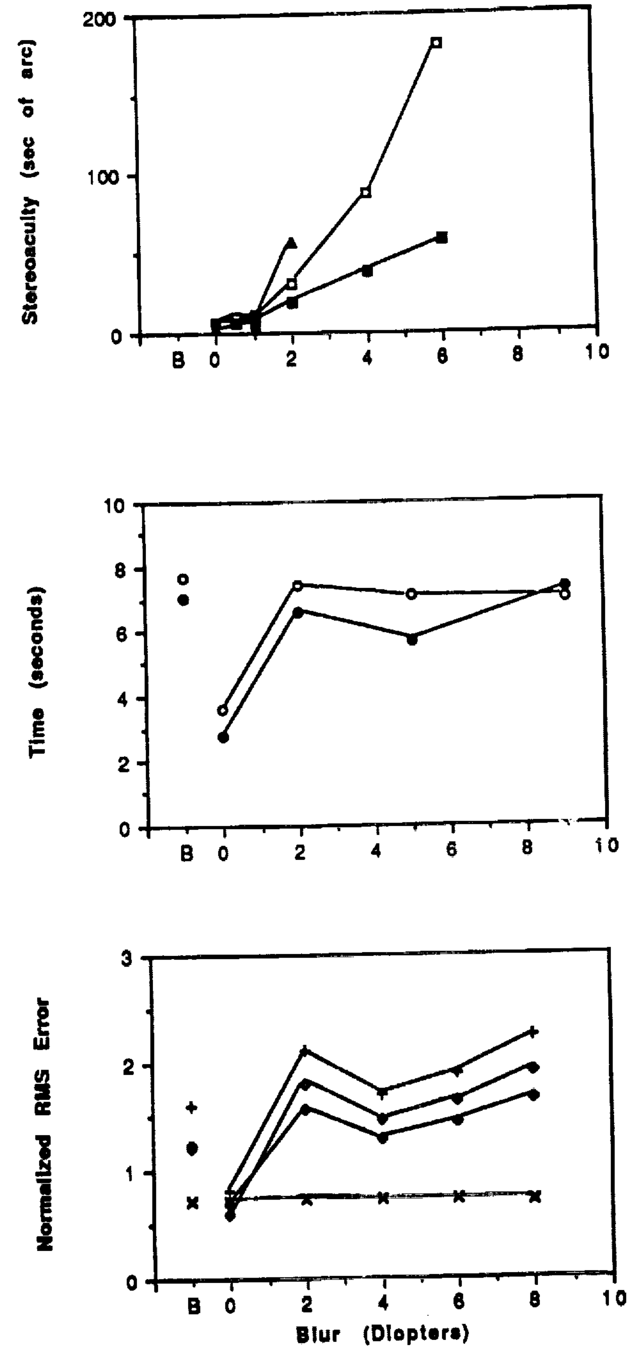

Figure 7. Blur Effects. The effect of spectacle blur on stereoacuity and task performance. Top: Data from Lit's (square) and Westheimer and McKee's (triangle) experiments. Middle: Mean completion time for the pick-and-place task versus blur. The circle symbol is for an average of seven trials, solid circle is for one trial. Bottom: Error in tracking vs. blur. We examined the error along the x [horizontal](cross), y [vertical](plus), z [zoom](diamond) axes and also in three dimensions (solid)

Previous Blur Studies

Previous studies of blur as the stimulus to accommodation have been carried out by Dr. Stephen Phillips in our laboratory. Two aspects of the blur signal are of particular interest: --- (i) the eccentricity of the stimulus with respect to the retinal fovea, and (ii) the spatial frequencies of the target before it is becomes the blurred retinal image.

Two examples of the effect of eccentricity on the static and dynamic tracking ability of the accommodative system are shown in Figures 8 and 9. It is clear that the ability of a defocused peripheral target evoking an accommodative response drops off rapidly outside the fovea; these results correlate with the decreased visual acuity. In normal viewing conditions vergence-accommodative synkinesis controls accommodation whenever a focusable target is more than several degrees off the line-of-sight.

Spatial frequencies between 1.0 c/deg and 25 c/deg (at a 0.63 contrast ratio, Cm) are effective as shown in the experiment of Figure 10. Here, several subjects are focusing at a 5.5 D and 0 D distant target through a range of spatial frequencies. When the spatial frequency go beyond the feasible range the subjects drift back to their bias set level (generally about 1.0 diopter, but for one of our subjects to about 2.0 diopter due to instrumental myopia). A summary figure , Figure 11, shows the envelope of responses to adequate and inadequate spatial frequency targets over a range of accommodative stimuli.

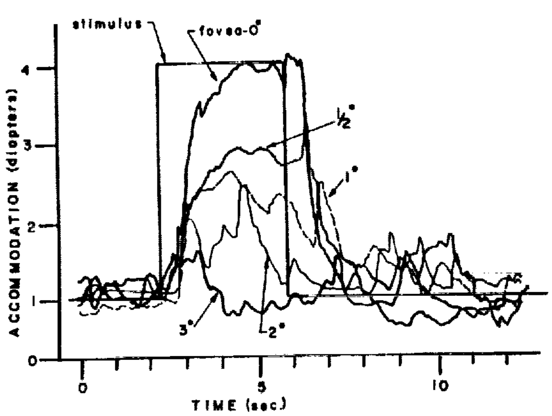

Figure 8. Accommodation response as a function of eccentricity. A 4 s duration step stimulus at 4 D produced an excellent response at 0 deg eccentricity, but even a 1/2 deg eccentricity greatly reduced response. Response at 2 deg is already likely only a searching stimulated by the subject noticing a change in light distribution. (Phillips, S. Thesis, 1974, University of California, Berkeley).

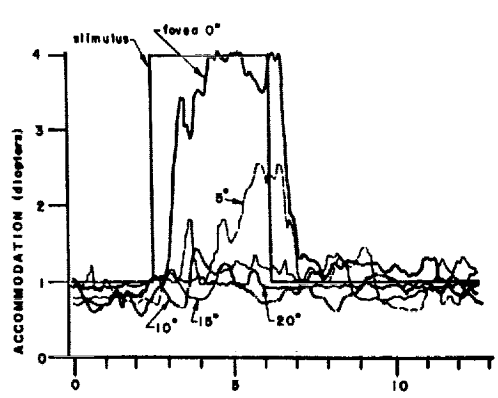

Figure 9. Accommodation Responses at Higher Eccentricities. In another subject, with excellent response at 0 deg eccentricity, little on no responses occurs at moderate eccentricities. (Phillips, S. Thesis, 1974, University of California, Berkeley).

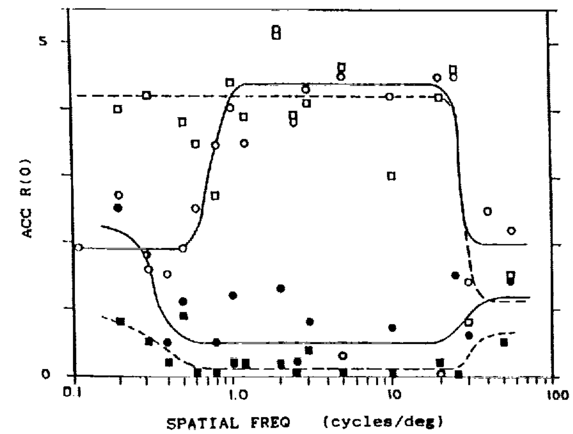

Figure 10. Range of spatial frequencies serving as adequate stimulus to accommodation. Accommodative stimuli, containing frequencies from 1.0 c/deg to 25 c/deg were adequate as shown in responses to 5 D and 0 D from a stimulus level of 1 D, for two subjects. Bias set level for one subject was 2 D. (Phillips, S. Thesis, 1974, University of California, Berkeley).

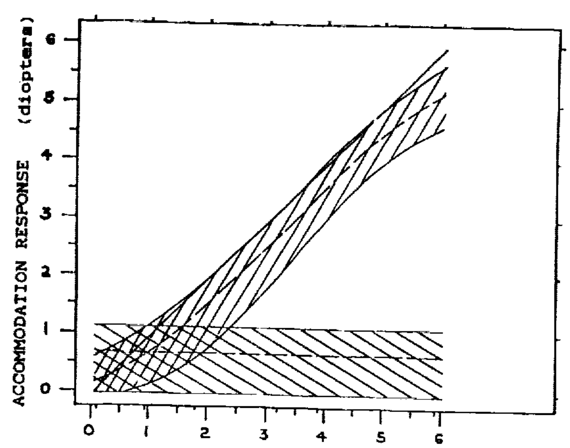

Figure 11. Envelopes of responses to adequate and inadequate stimuli. Accommodative stimuli containing spatial frequencies from 1.0 c/deg to 25 c/deg were able to drive accommodation accurately over the range of diopters from 0 to 6 D (upper envelope). Stimuli containing only frequencies outside that range were inadequate (lower envelope). (Phillips, S. Thesis, 1974, University of California, Berkeley).

Visual Search

Visual scanning behavior, or how humans search their visual field, can be investigated through the use of the helmet-mounted display. These types of investigations of visual search would be useful in the development of electro-optical detection devices and manned systems designs. Much research has been done concerning visual scanning behavior using eye-movement data; however, head movements are also an interactive part of the visual scanning process, and is an area worth investigating. With the helmet-mounted display, viewing monitor windows limit the visual field (the area of extent of physical space visible to an eye in a given position) to a measurable amount, while the field of view (the extent of the object plane visible through, or imaged by an optical instrument) is digitally controllable. Thus, the subject is induced to use head movements with limited eye movements to search a given scene in a simulated field.

Figure 12 shows an example of head-movement data superimposed on the searched scene. A 3120 Silicon Graphics Iris was used to create and display this scene of robots on a simple background. Through the HMD monitors, only a windowed portion of the scene was visible to the subject at a time (see Figure 13). As the subject turned his/her head, a perspective projection of the scene was displayed at an appropriate angle. The resulting effect was one of looking at a large two-dimensional wall. Figure 14 shows the actual display appearing on the HMD monitors while the subject viewed a central portion of the scene in fig 12. Here, the simulated dimensions used were of a 10 ¼' x 7 ¾' wall viewed from a distance of 2'. A 60-degree head rotation was required to scan the entire scene.

Obviously, there are many factors which can affect visual scanning behavior. These include display resolution; number, orientation, and size of targets; amount of clutter (non-target objects resembling the target); field of view; noise; and peripheral visual acuity. Various eye movement studies on visual search have been conducted investigating the effect of the visual lobe area on visual search [10]-[12]. The visual lobe area is defined as the area surrounding the central fixation point from which information can be obtained in a single glance. As the complexity of the background in which the target is embedded is increased, the size of the visual lobe area decreases. Ultimately, the visual lobe area is a major factor influencing search time. This would be an interesting subject to investigate further using head-movement data.

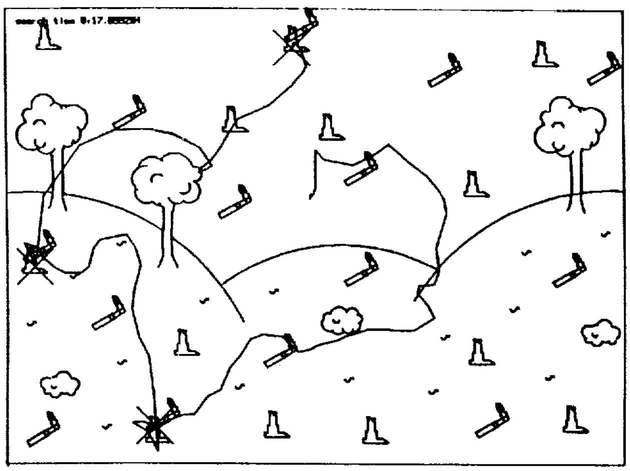

Figure 12. Head Movement Driven Visual Search. A typical search path (heavy line) with X's marking acquired targets, complete robots, in a field with clutter (partial robots) demonstrates that subjects do not make systematic searches.

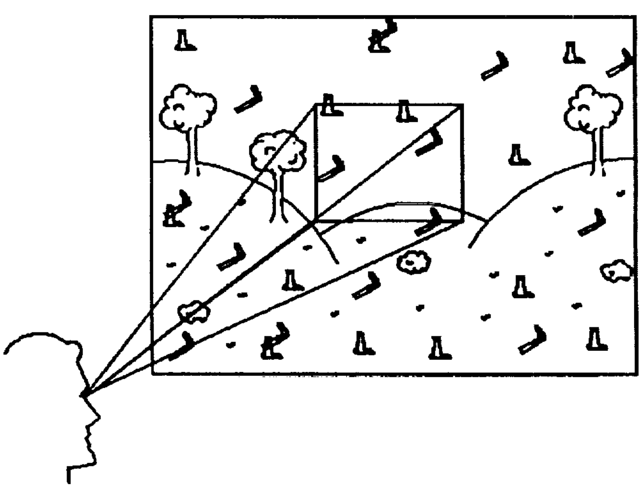

Figure 13. Visible Window Control by Head Direction. To study visual search, we limited the solid window angle on a large display solid angle. This forced subjects to search the space with a combination of head and eye movements.

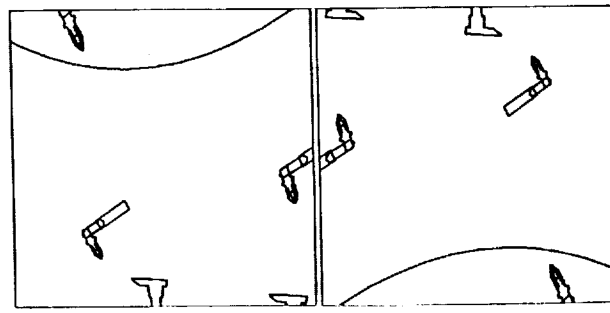

Figure 14. The Visual Search Display. The HMD window provides only a limited view of the scene. In the figure the left image is inverted as in the actual display because the left viewfinder of the HMD is upsidedown.

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